

VOLTAGE LEVEL TRANSLATOR FOR TRANSLATING LOW TO HIGH VOLTAGE LEVELS IN DIGITAL INTEGRATED CIRCUITS

5 Field of the Invention

This invention relates to voltage level translators for translating low to high voltage levels in digital intergrated circuits. Ths invention further relates to a method for translating high voltage levels in digital intergrated circuits.

Background of the Invention

10 Advances in semiconductor fabrication and manufacturing techniques have led to smaller, denser and more complex integrated circuits. Digital integrated circuits are spearheading the drive to increased densities and smaller geometries. At the same time digital integrated circuits are also being operated at higher speeds. The combination of increased density and higher speeds also results in increased power
15 dissipation, which in turn increases the temperature of the device thereby reducing its reliability. Inorder to counteract the increased power dissipation modern devices are increasingly being designed to operate at reduced voltage levels. Current technology supports digital integrated circuits based on transistors with gate lengths reduced to 0.12u with corresponding supply voltages as low as 1.2V. However the IO
20 requirements of digital integrated circuits are defined by the requirements of external devices and hence remain at voltage levels that are significantly higher than the core circuitry. Typical IO voltages remain at a 3.3 V to 5.0V level while the core circuitry operates at 1.2V. To operate in such an environment it is necessary to use voltage level translators, which translate signals at the lower voltage level of core logic to the
25 higher lower voltage levels of the IO.

A transistor operating at a higher voltage such as 3.3V is designed to have a relatively long gate length to avoid punchthrough. At the same time, the transistor must also have a thicker gate oxide to prevent oxide break down. These transistors are relatively high voltage devices and are termed as 3.3V devices. If a 3.3V device is
30 used for operation at lower voltage levels such as 1.2V, it provides relatively poor performance in term of speed owing to higher channel resistance and higher gate capacitance. In contrast, transistors operating at lower voltage levels are designed

with shorter channel lengths to reduce the channel resistance and gate capacitance as the breakdown voltage requirements are lower. The lower resistance and gate capacitance enable significant increase in speed of operation besides providing higher density. Transistors which are used for lower voltages are low voltage devices and if
5 designed for 1.2V operation are termed as 1.2V devices in the context of this document. Low voltage transistor models are not designed for use with higher voltages because of the risk of punchthrough and gate oxide breakdown.

To exploit the advantages of low voltage core logic and to make it compatible with the high voltage IO interface it is necessary to use a voltage level translator.
10 While there are many techniques used to realize voltage level translators almost all of them produce voltage level translators that do not achieve equal rise and fall time under varying operating conditions resulting in the generation of unwanted glitches and delays.

Modern **FPGAs** utilize core voltages as low as 1.2 volts while IO voltage
15 remains at 3.3 volts. Signals from the 1.2 volt core, if fed directly to circuitry working at higher voltage 3.3 volts will result in unnecessary power dissipation, since the 1.2 volt signal from the core logic will always keep the IO logic's **PMOS** transistor **ON** as its source is connected to 3.3 volts. To overcome this problem it is necessary to incorporate voltage translator circuitry that converts the 1.2 volts signal
20 to 3.3 volts signal without any static power dissipation.

FIG. 1 shows a voltage translator according to the prior art as disclosed in **U.S. Patent No. 5,422,523**. In this patent the low voltage input **IN** is fed to the gate of NMOS transistor **104** and also to the gate of a second NMOS transistor **103** through inverter **LV**. Inverter **LV** operates at a low voltage (**VDDL**). Transistors **103**
25 and **104** are biased through transistors **101** and **102**. The gate of transistor **102** is connected to the output **OUT 1**, while the gate of transistor **101** is connected to node **206**. When **IN** rises from 0 volts to **VDDL**, NMOS transistor **104** is turned-on which reduces the voltage at node **206**. This voltage reduction turns-on PMOS transistor **101** and increases the voltage at **OUT 1**. The output of **LV** at this time is 0 volts
30 which turns-off NMOS transistor **103**. The increase in voltage at **OUT 1** reduces the conduction level of PMOS transistor **102** which further decreases the voltage at **206**. This cycle is repeated until the voltage at **OUT 1** rises to **VDDH**.

Similarly, when **IN** falls from **VDDL** to 0 volts, NMOS transistor **104** turns-off and NMOS transistor **103** turns-on, pulling down **OUT 1**. The reduction in voltage at **OUT 1** turns-on PMOS transistor **102** slightly which in turn increases the voltage at node **206**. This condition decreases the conductivity of PMOS transistor **101** leading to further reduction in the voltage at **OUT 1**. This recursive feedback ultimately reduces the voltage at **OUT 1** to 0 volts.

The drawback with this approach is that it is difficult to achieve equal rise fall times under different operating conditions. This difficulty arises from unwanted capacitance effects which become more prominent at low voltages such as 1.2 volts. Also, since the difference between 1.2 volts and 3.3 volts is large the variations of various parameters with operating conditions has a pronounced effect on circuit performance.

Summary of the Invention

An object of the invention is to provide a method and device to reliably interface the signals from the core logic to the IO pads when these operate at different voltages. Another object of the invention is to provide a voltage translator circuit which achieves equal delays and rise fall time under different operation conditions. It is yet another object of the invention to overcome the disadvantages arising from the bootstrapping of the IO stages.

To achieve these and other objectives this invention provides an improved low voltage to high voltage translator for digital electronic circuits providing reduced rise times, fall times and transition times that remain independent of operating conditions. This is accomplished by modifying a conventional low-to-high voltage translator comprising a first high-voltage switch driven by the input low-voltage signal, a second high-voltage switch driven by the complement of the input low-voltage signal, the output of the first high-voltage switch enabling an active switched load connected to the output of the second high-voltage switch when the first high-voltage switch is OFF and disabling it when the first high-voltage switch is ON, the output of the second high-voltage switch enabling an active switched load connected to the output of the first high-voltage switch when the second high-voltage switch is OFF and disabling it when the second high-voltage switch is ON, the output from the low-to-high voltage translator being provided by the output from the second high-voltage

switch to include a switched active pull-up at the output of the first high-voltage switch, controlled by the input low-voltage signal and gated by the output from the low-to-high-voltage translator and a switched active pull-down at the output of the first high-voltage switch, controlled by the input low-voltage signal and gated by the complement of the output from the low-to-high-voltage translator, so as at to provide regenerative pull-up and pull-down that also counteracts the bootstrap capacitance at the output of the first high-voltage switch.

Brief Description of the Drawings

FIG. 1 shows a voltage translator according to the prior art.

10 **FIG. 2** shows the schematic of a voltage translator in accordance with the present invention.

FIG. 3a shows the voltage waveforms of proposed voltage translator.

FIG. 3b shows the comparative bootstrapping effect in the prior art and present invention.

15 **FIG. 4** shows the simulation waveforms of the prior art circuit as well as the proposed circuit for typical models.

FIG. 5 shows the variation in the simulation waveforms using slow models.

FIG. 6 shows the variation in the simulation waveforms using slowfast models (i.e., NMOS is slow and PMOS is fast).

20 **FIG. 7** shows the comparison of waveforms showing the effect of bootstrap capacitance.

Detailed Description

The invention will now be described in accordance with the accompanying drawings. **FIG. 2** shows a preferred embodiment of the invention. The input **IN** from the core logic is connected to the gates of transistors **N1**, **P4**, **N3** and to the gate of NMOS transistor **N2** through inverter **LV1**. Inverter **LV1** is an inverter driven by low voltage. The source of PMOS transistor **P4** is connected to low voltage source (**VDDL**), and the drain is connected to NMOS transistor **N5**. The gate of transistor **N5** is connected to the output **OUT 2**, and the second conducting terminal is connected to line **402**. Voltage source **VDDH** is connected to the source of PMOS

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transistors **P1** and **P3**. The gates of the PMOS transistors **P1** and **P3** are cross coupled to drains **402**, **404 (OUT 2)** of the NMOS transistors respectively.

The source of NMOS transistor **N1** is connected to **GND** and its drain is connected to line **402**. The gate of transistor **N2** is connected to the output of **LV1**.

5 The source and drain of **N2** are connected to **GND** and **OUT 2** respectively while the conducting terminals of NMOS transistor **N3** are connected to lines **402** and **405**. The source of NMOS transistor **N4** is connected to **GND** and its drain is connected to line **405**. The gate of transistor **N4** is connected to the output of inverter **HV1** through line **407**. **OUT2** is connected to the input of inverter **HV1** while the gate of MOS
10 transistor **N5** is connected to **OUT 2**.

When input **IN** is at High voltage (e.g. 1.2 V), PMOS transistor **P4** is OFF and NMOS transistor **N1** is conducting pulling line **402** to **GND**. This makes PMOS transistor **P1** ON. The LOW output of **LV1** turns-off NMOS transistor **N2**. The conduction of PMOS transistor **P1** causes node **OUT 2** to go High. The High voltage
15 (e.g. 3.3V) at **OUT 2** causes inverter **HV1** to make line **407** low thereby turning OFF NMOS transistor **N4** while at the same time turning OFF PMOS transistor **P3** and keeping NMOS transistor **N5** conducting.

When the input **IN** goes from high (1.2V) to low (0V) voltage the gate of NMOS transistor **N1** goes from high to low. The bootstrap capacitance at line **402**
20 takes voltage at this net below 0 volts which delays the process of making **P1** OFF. If slow models are used this delay is increased drastically. **P4** and **N5** are used to overcome this problem. The gate of **N5** is connected to **OUT 2** which is high voltage (3.3V), this keeps **N5** ON. As soon as **IN** goes from high to low, the MOS transistor **P4** becomes ON. Because of bootstrapping **N1** tries to take line **402** below 0 volts but
25 the combination of **P4** and **N5** opposes this effect and minimizes the bootstrapping effect. The circuitry tries to balance operation under all operating conditions. **LV1** makes line **406** high voltage (1.2V) which makes NMOS transistor **N2** ON. This reduces voltage at **OUT 2**. Reduction in voltage at **OUT 2** makes PMOS transistor **P3** ON. This further increases the voltage at line **402** thereby making PMOS
30 transistor **P1** conduct less thereby reducing voltage at **OUT 2**. As a result, PMOS transistor **P3** turns ON harder and this positive feedback ultimately makes **OUT 2** 0 volts. As **OUT 2** becomes 0 volts PMOS transistor **P1** turns fully OFF and PMOS transistor **P3** turns fully ON. As soon as the falling voltage at **OUT 2** crosses the trip

point level of inverter **HV1** line **407** becomes high (3.3V) turning NMOS transistor **N4** ON. NMOS transistor **N3** is **OFF** since its gate is connected to **IN** which is 0 volts. In the final stable condition when **IN** and **OUT 2** both are 0 volts there is no conduction path between **VDDH** and **GND** or between **VDDL** and **GND**. Thus there is no static power dissipation in the circuit.

Similarly, when input **IN** makes a transition from low voltage to High voltage e.g. 0 volts to 1.2 volts the circuit acts to make **P1** ON as early as possible so that output **OUT 2** reaches **VDDH** volts quickly. When both **IN** and **OUT 2** are at 0V NMOS transistor **N5** is OFF and NMOS transistor **N4** is ON. As **IN** increases from 0 volts to 1.2 volts NMOS transistor **N1** and NMOS transistor **N3** start conducting. Since **OUT 2** is still 0 volts inverter **HV1** keeps NMOS transistor **N4** ON. The combination of NMOS transistors **N3**, **N4** and **N1** pulls down line **402** to 0 volts faster than the case when there is only **N1** to pull it down. Inverter **LV1** acts to make **N2** OFF. With **P1** beginning to conduct the voltage at **OUT 2** starts increasing and as **OUT 2** reaches the trip point of **HV1** the voltage at line **407** reaches 0 volts. This makes NMOS transistor **N4** OFF. The trip point of **HV1** is adjusted according to the amount of time for which NMOS transistor **N4** is to be kept ON. As **OUT 2** starts increasing PMOS transistor **P3** starts turning OFF. This will further reduce the voltage at line **402** and ultimately this feedback will take node **OUT 2** to 3.3 volts. This makes PMOS transistor **P3** turn OFF and line **402** becomes 0 volts. In the final stable condition when **IN** is 1.2 volts and **OUT 2** is 3.3 volts there is no conduction path between **VDDH** and **GND** or between **VDDL** and **GND**. Thus there is no static power dissipation in the circuit.

The circuit of this invention compensates for the effect of bootstrapping capacitance and also improves transition times. Low to high transitions are improved by incorporating **N3** and **N4**. **N4** remains ON for a very short time just to make **P1** ON with greater power than if only **N1** pulls line **402** down. Thus **N3** and **N4** act only to improve the initial voltage fall at line **402**. Similarly high to low transitions are improved by compensating effects of bootstrapping capacitance. The circuit also works well for converting 3.3V to 5V.

FIG. 3a shows voltage waveforms at nodes **IN** and **OUT2** for proposed voltage level translator. The dotted line waveform shows the input waveform at **IN**, while the solid line shows output voltage at node **OUT2**.

FIG. 3b shows the voltage waveform at line **402** for an improved voltage level translator according to this invention. The solid line shows voltage at **402** while the dotted line is the waveform at line **402** without using the MOS transistors **N3**, **N4**, **N5** and **P4**. The effect of the bootstrap capacitor is clearly visible by seeing dotted waveform when voltage at line **402** starts rising. When Input **IN** falls, the voltage at line **402** should rise but because of bootstrapping capacitance the voltage goes below 0 volts. This effect is reduced to a large extent as shown by the solid line waveform. Similarly when **IN** goes from 0 volts to 1.2 volts because of the MOS transistors **N3** and **N4** the initial rate of fall at line **402** becomes faster as shown by the solid line waveform.

FIG.4 shows simulation waveforms of the prior art circuit shown in **FIG.1** and the proposed circuit shown in **FIG.2** along with the input **IN**. **OUT1** and **OUT2** are the voltages at the output node of the prior art and proposed circuits respectively under typical operating conditions. The two waveforms are superimposed and the rise and fall delays are almost the same.

FIG. 5 shows the simulation results when models are changed from typical to slow. The proposed circuit output **OUT2** shows better rise and fall delays and transistion times.

FIG. 6 shows the simulation results when models are changed from typical to slowfast i.e **NMOS** is slow and **PMOS** is fast. The proposed circuit output **OUT2** shows better rise and fall delays and transistion times. **NET206** shows the voltage variation at **206** for the prior art circuit of **FIG.1** whereas **NET402** shows the waveform at **402** in the improved circuit of **FIG.2**.

FIG. 7 shows the simulation waveforms at nets **402** and **206** under slowfast models. The waveform clearly shows the reduction in bootstrap effect because of which the voltage rise at **402** is faster. The falling at **402** is also better because of the inclusion of **NMOS** transistors **N3** and **N4**.

While the foregoing description related to an application comprising 1.2V and 3.3V circuitry, the invention is by no means limited to these operating voltage levels. As any with ordinary skill in the art will realize, the principals employed will work equally well in applications involving other voltage levels. Accordingly, the invention is by no means limited by the foregoing examples but is bounded only by the scope of the claims.